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Hoff

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(54) **MAGNETO-RHEOLOGICAL INERTIAL DAMPING SYSTEM FOR LIFT TRUCKS**

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(51) **Int. Cl.**

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B60G 17/016	(2006.01)
B60G 17/08	(2006.01)

(52) **U.S. Cl.** **280/5.5**; 280/755; 180/282; 414/631; 187/222

(58) **Field of Classification Search** 280/5.507, 280/5.5, 5.515, 5.519, 6.15, 6.159, 6.157, 280/755; 180/282; 414/631, 630; 187/222, 187/224, 232

See application file for complete search history.

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Primary Examiner—Paul N Dickson
Assistant Examiner—Keith Frisby
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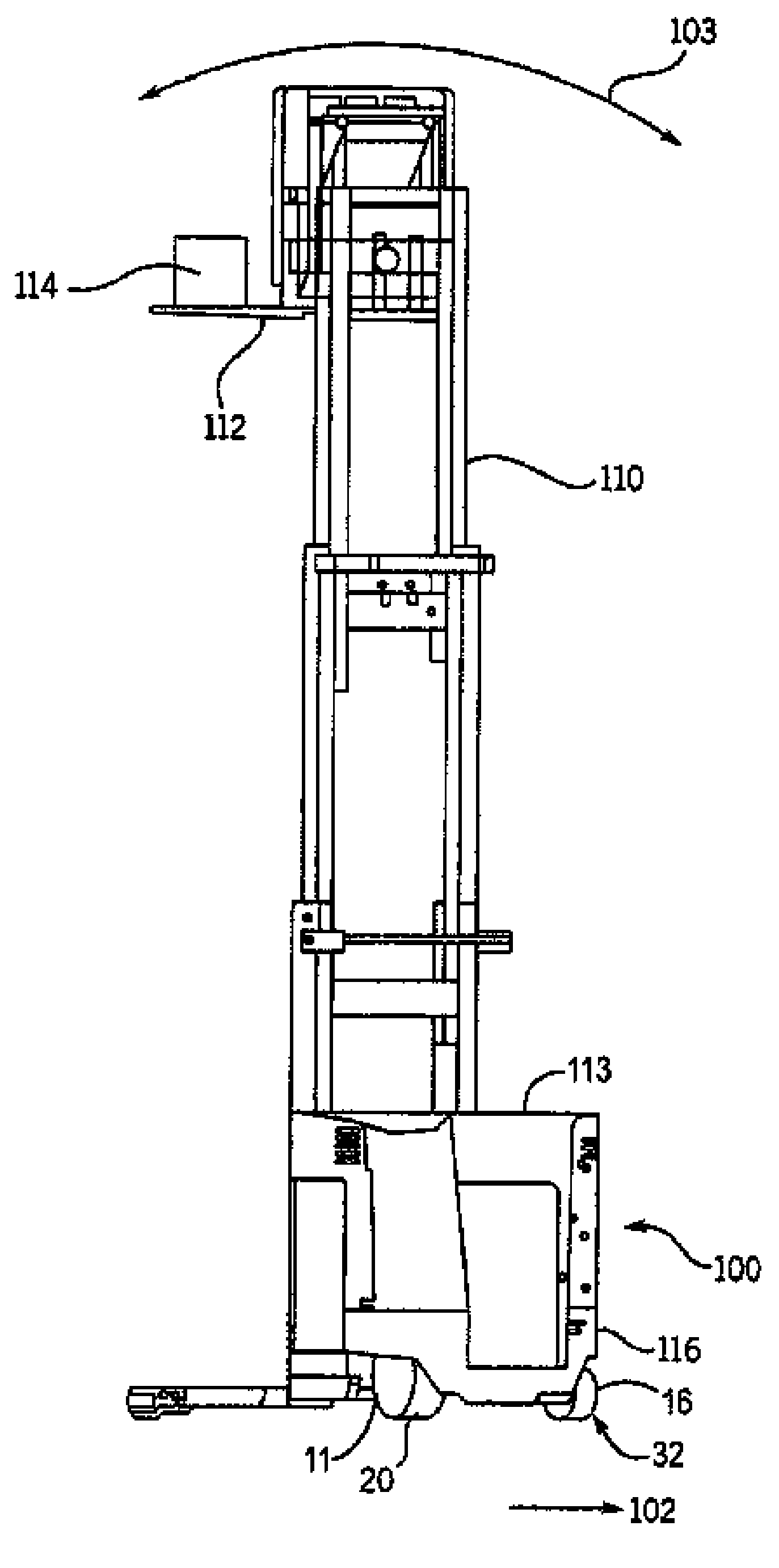
(57) **ABSTRACT**

A lift truck includes a magneto-rheological damper coupled between the base frame and a frame holding a vertically sprung suspended wheel. The damper is electrically connected to a vehicle control system, which increases and decreases the damping force as a function of at least one of a weight of a load on the forks of the lift truck, a height of the mast of the lift truck, and a speed of the lift truck. As the weight of the load, height of the mast and speed of the vehicle increase, the damping force is increased. As the weight of the load, height of the mast, and speed of the vehicle decrease, the damping force is decreased. When the damper is activated to increase the damping force, the truck can maintain a four point stance, providing a larger footprint for the center of gravity, thereby limiting truck sway or oscillation. When the damper is not active, or the damping force is increased, as, for example, during unloaded operation, the suspension of the truck is relatively soft, providing a smoother ride, thereby increasing operator comfort and productivity.

20 Claims, 10 Drawing Sheets



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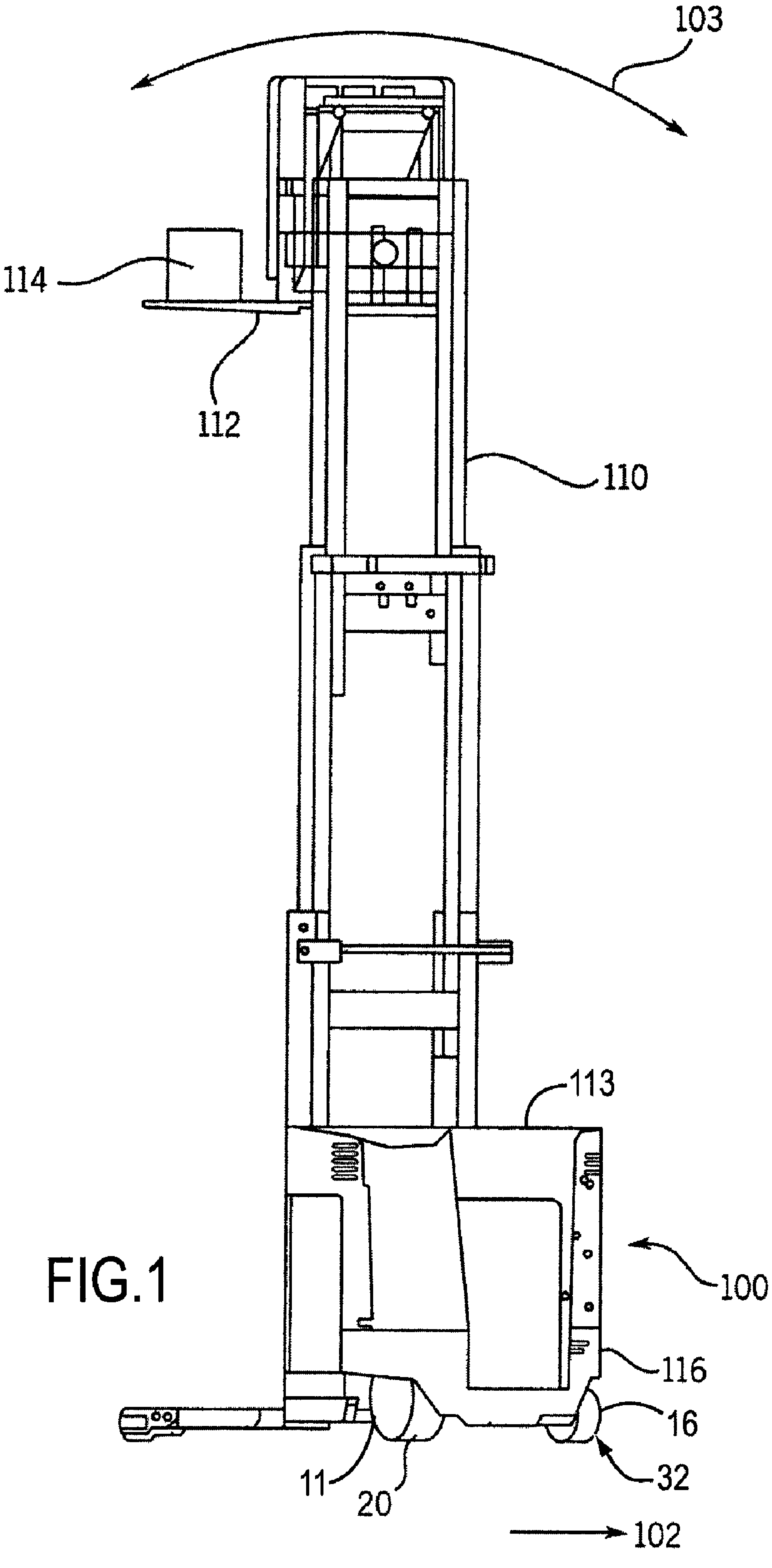


FIG.1

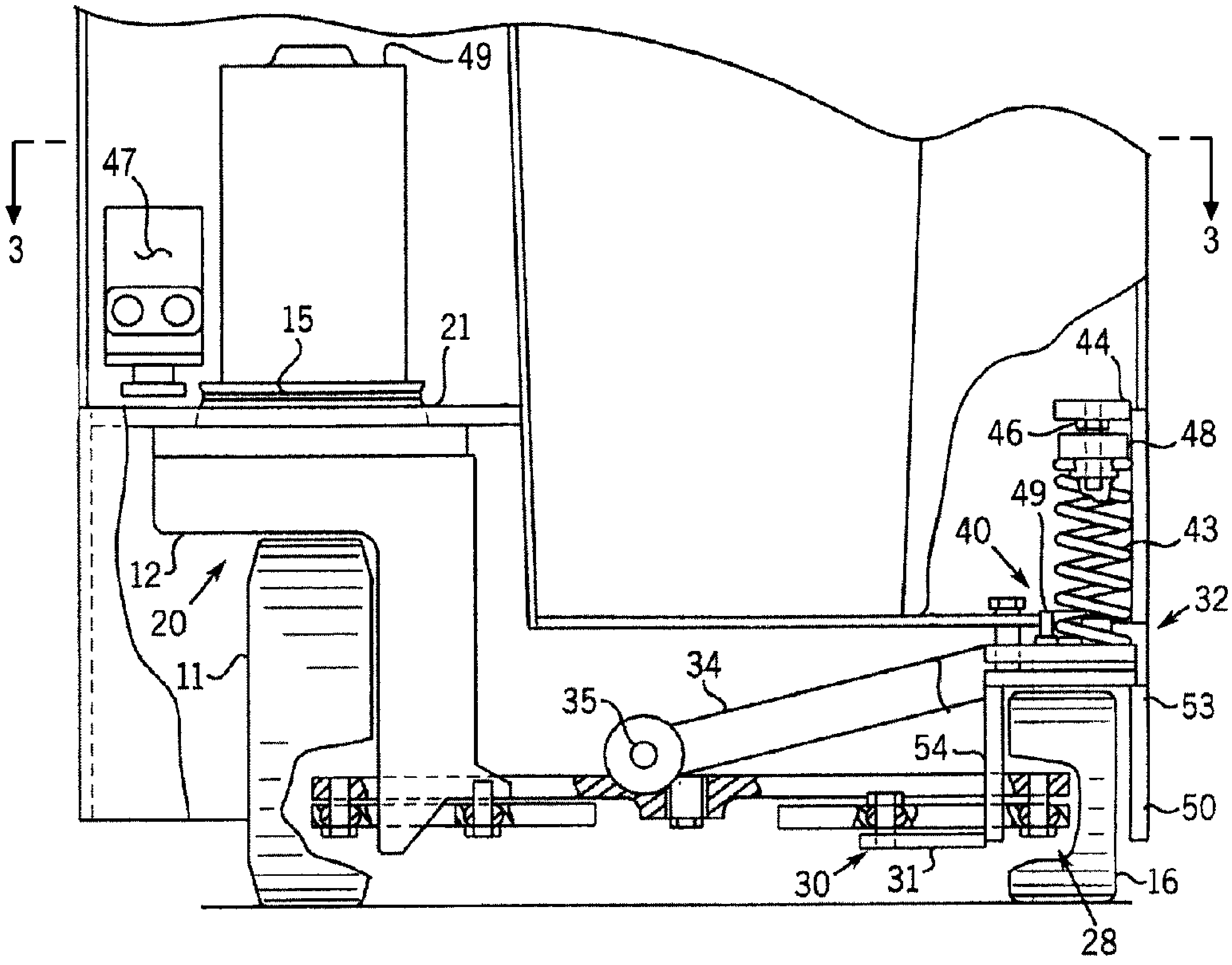


FIG. 2

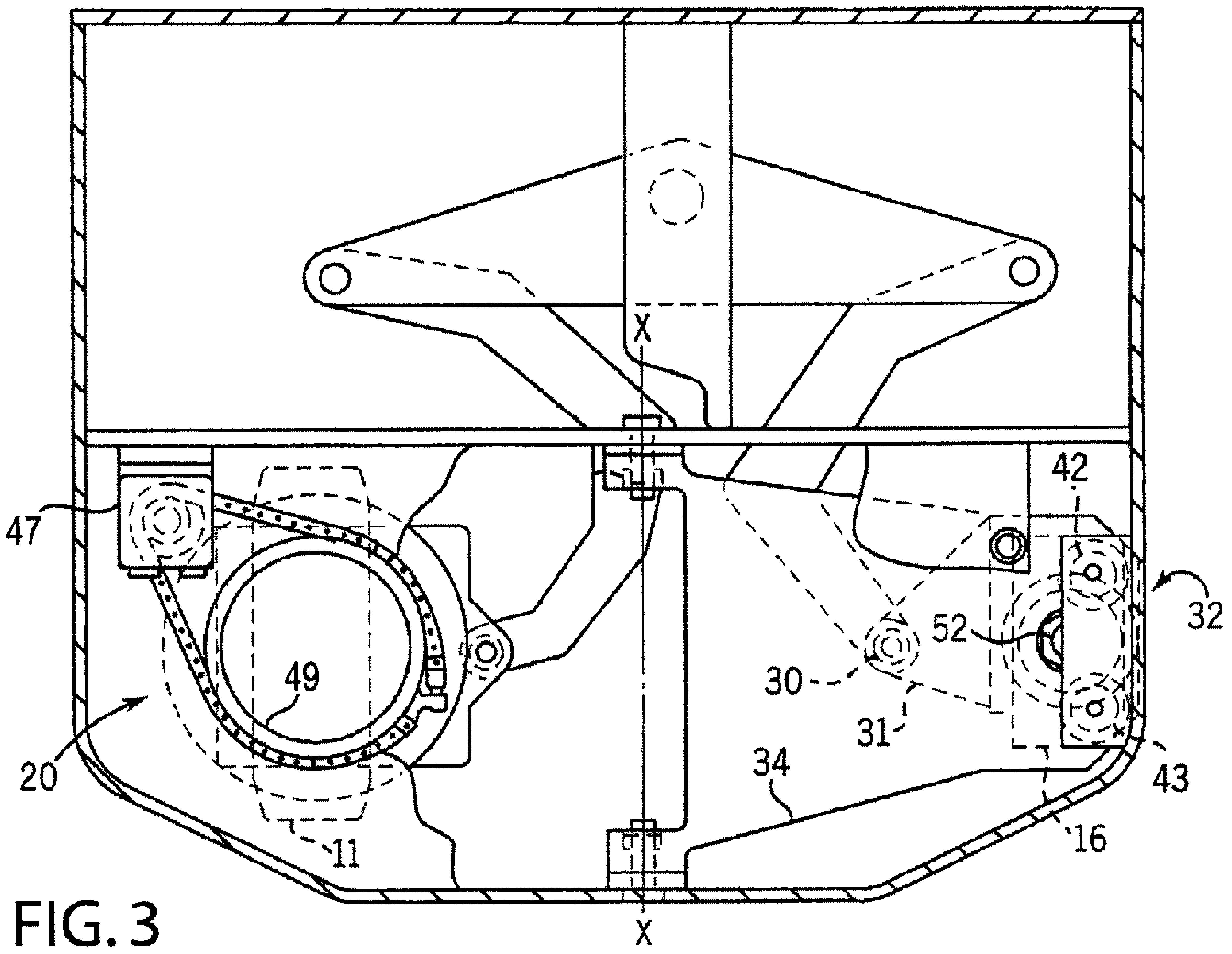
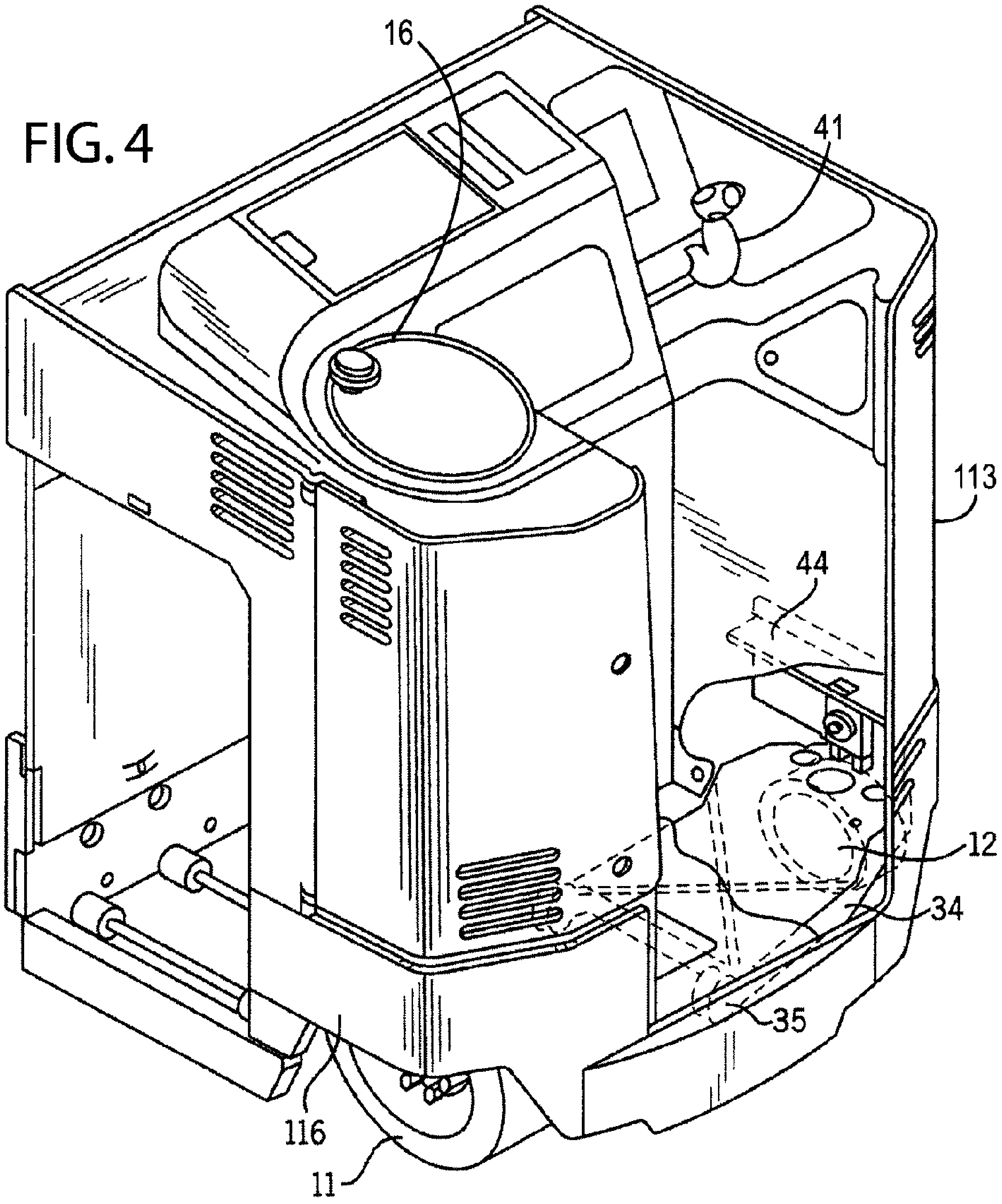


FIG. 3

FIG. 4



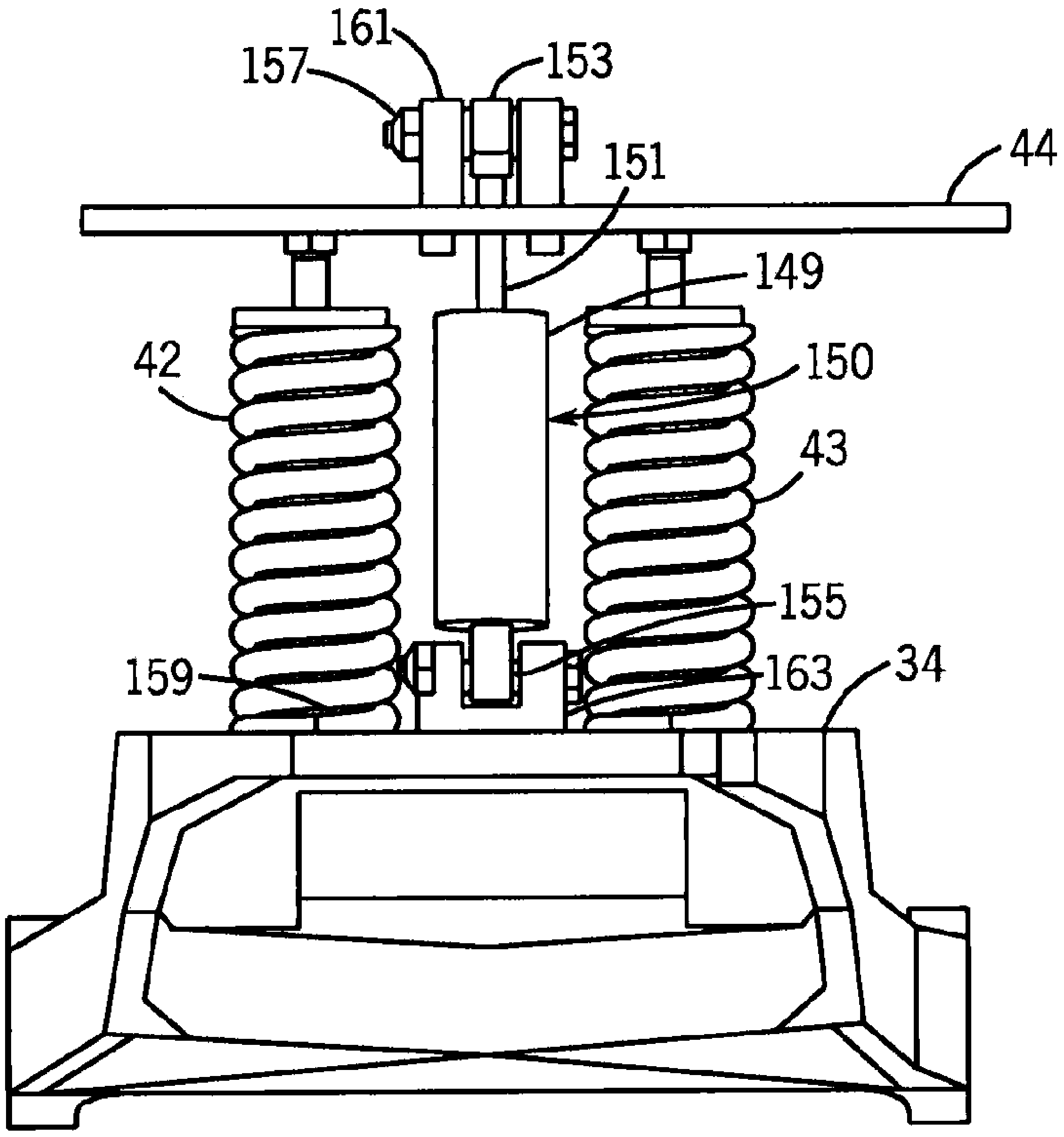

161
157
153
151
44
149
42
150
43
155
159
163
34

FIG. 5

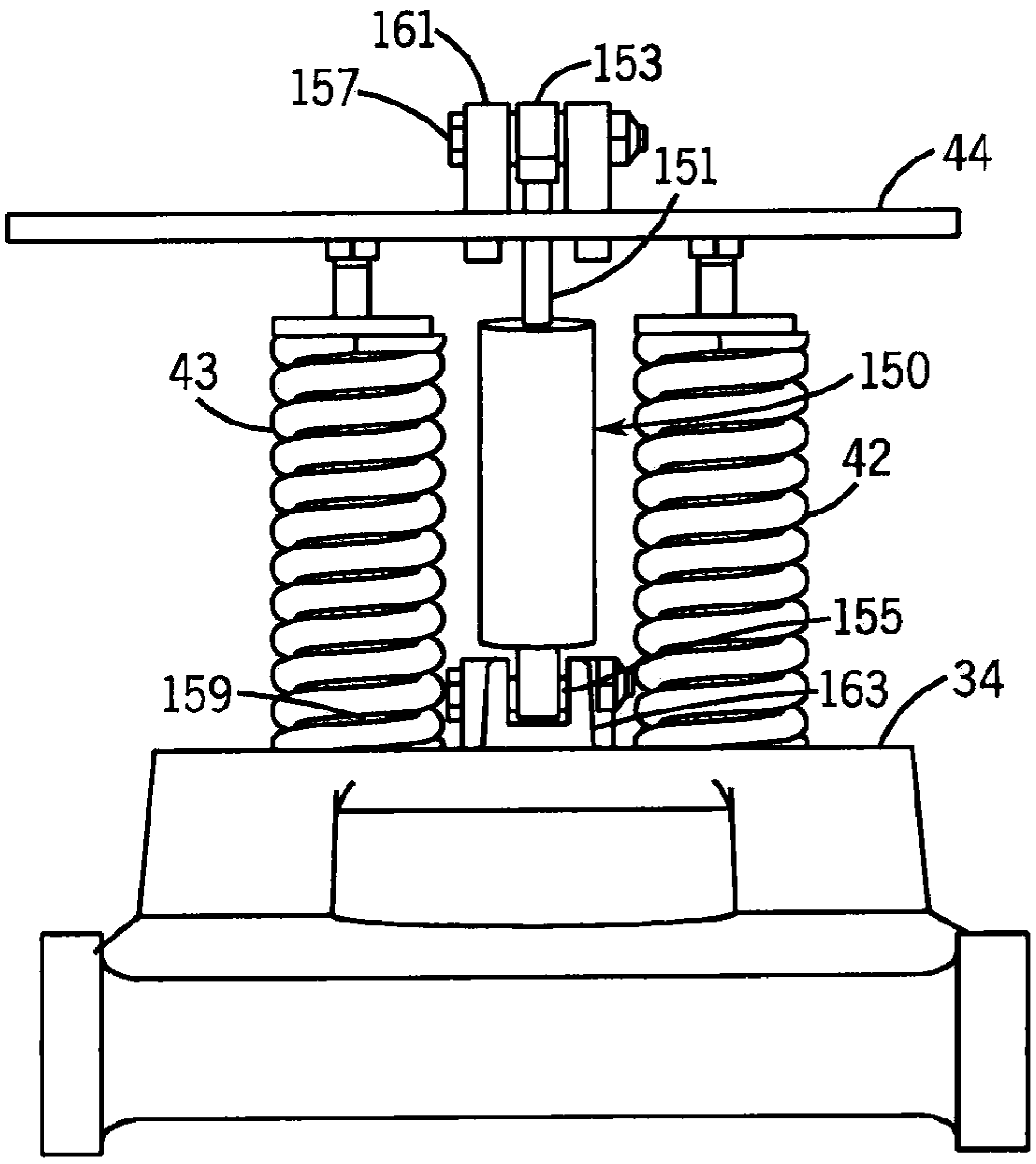

161
157
153
151
44
43
150
42
155
159
163
34

FIG. 6

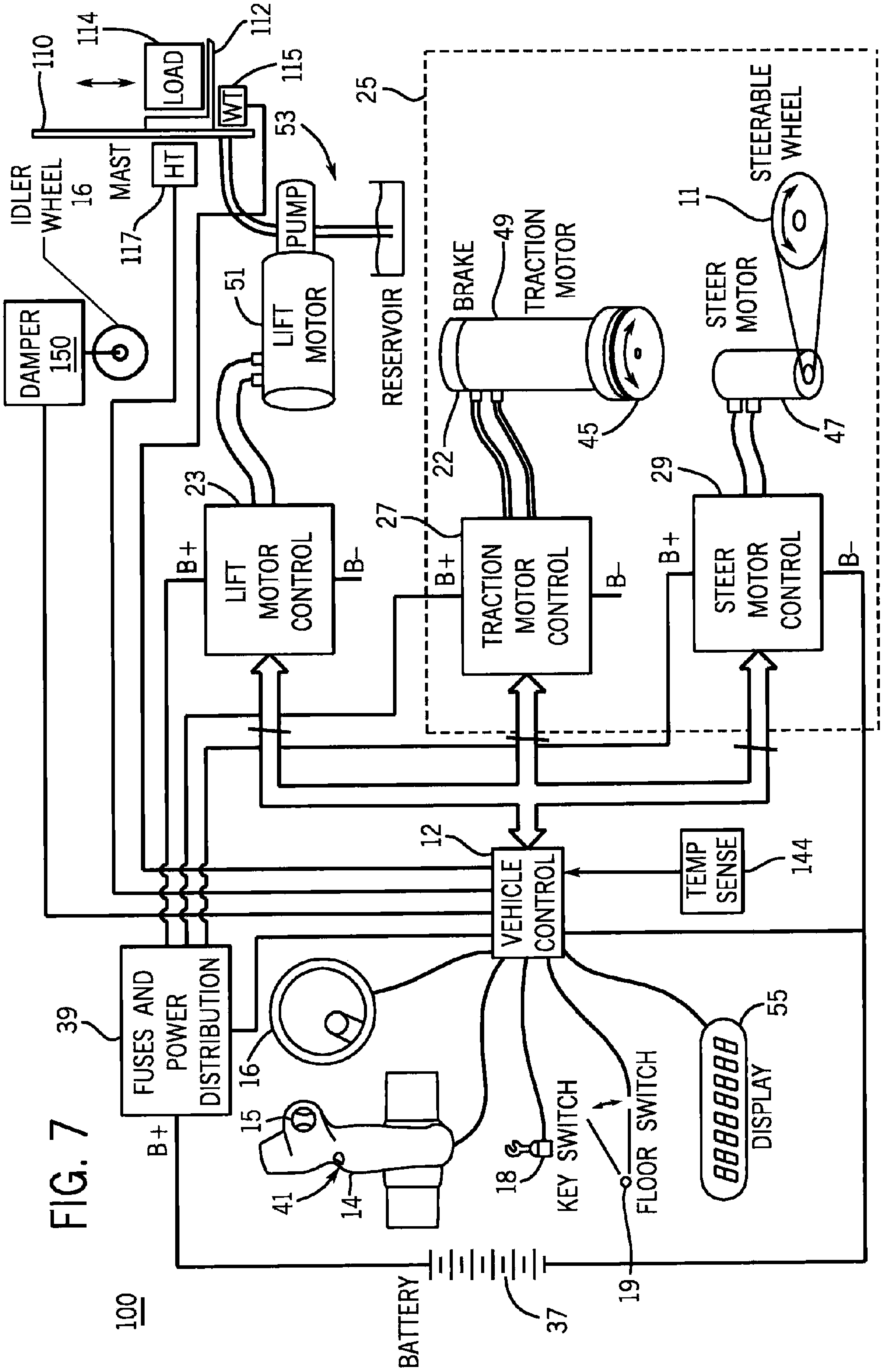

100
IDLER WHEEL 16
DAMPER 150
MAST
110
114
LOAD
112
115
WT
HT
117
53
PUMP
LIFT MOTOR
51
RESERVOIR
25
STEERABLE WHEEL
11
BRAKE
49
TRACTION MOTOR
45
22
STEER MOTOR
47
23
B+
LIFT MOTOR CONTROL
B–
27
B+
TRACTION MOTOR CONTROL
B–
29
B+
STEER MOTOR CONTROL
B–
12
VEHICLE CONTROL
TEMP SENSE
144
39
FUSES AND POWER DISTRIBUTION
B+
16
15
41
14
18
KEY SWITCH
FLOOR SWITCH
19
55
DISPLAY
BATTERY
37

FIG. 7

FIG. 8

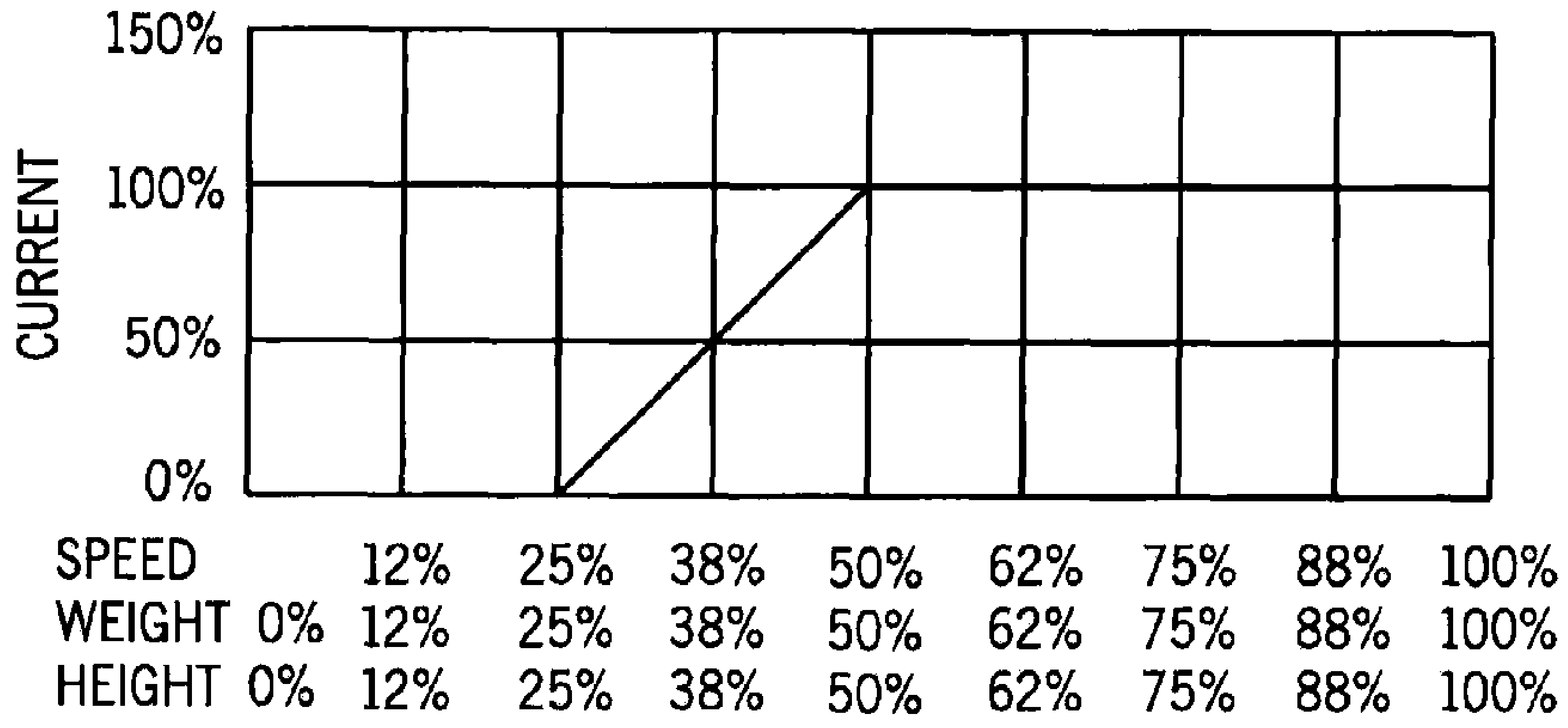
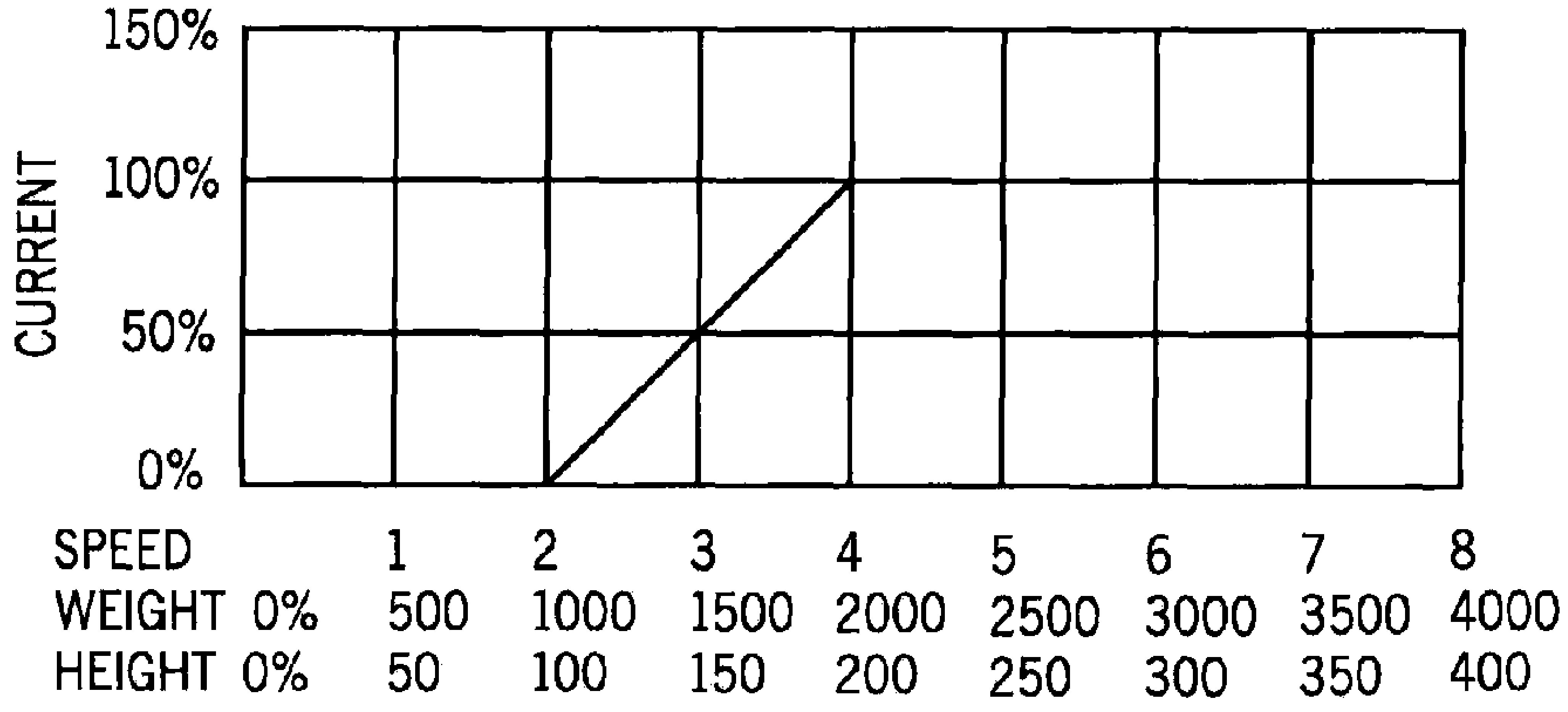

CURRENT
150%
100%
50%
0%
SPEED 12% 25% 38% 50% 62% 75% 88% 100%
WEIGHT 0% 12% 25% 38% 50% 62% 75% 88% 100%
HEIGHT 0% 12% 25% 38% 50% 62% 75% 88% 100%

FIG. 9


CURRENT
150%
100%
50%
0%
SPEED 1 2 3 4 5 6 7 8
WEIGHT 0% 500 1000 1500 2000 2500 3000 3500 4000
HEIGHT 0% 50 100 150 200 250 300 350 400

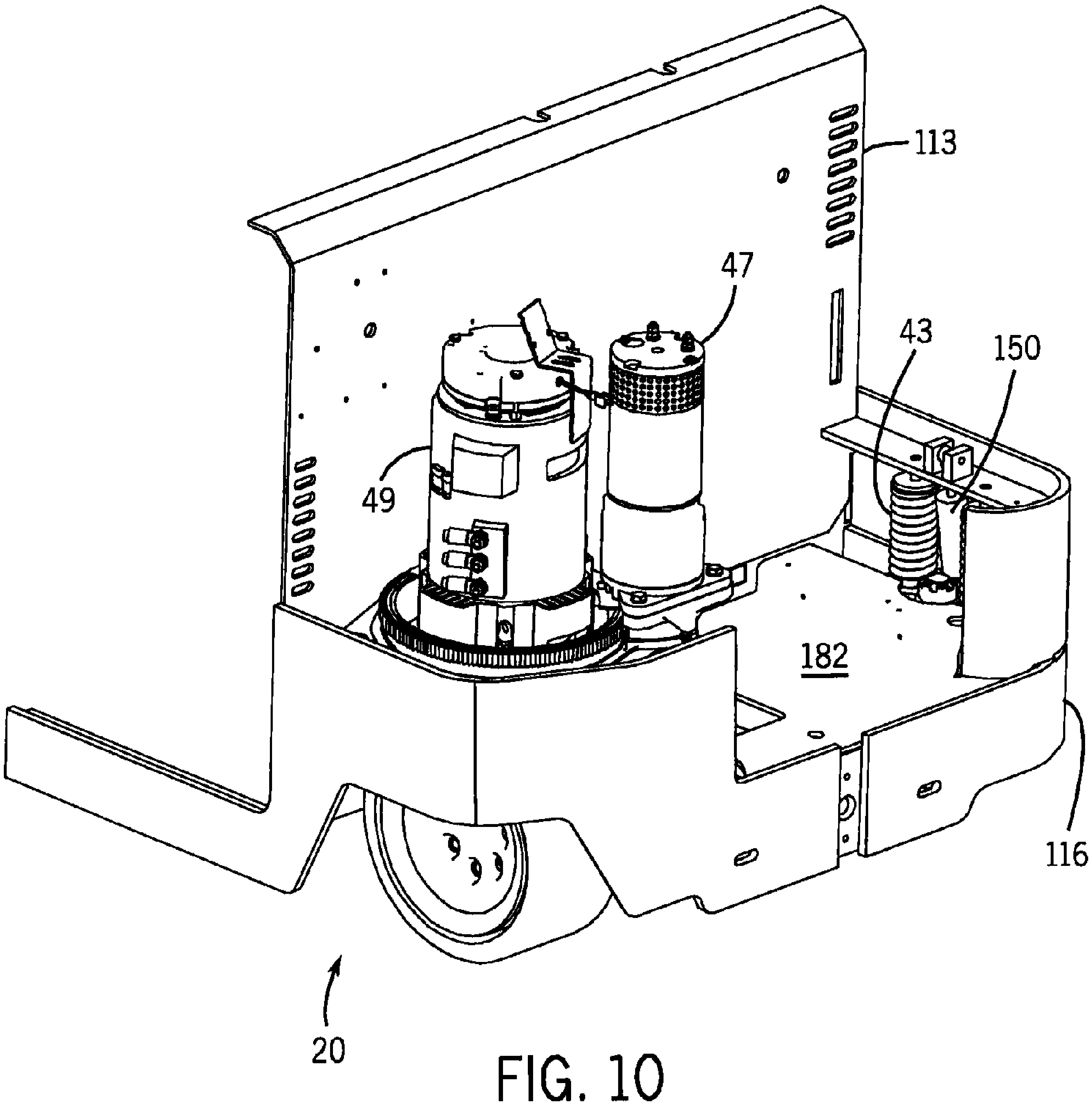


FIG. 10

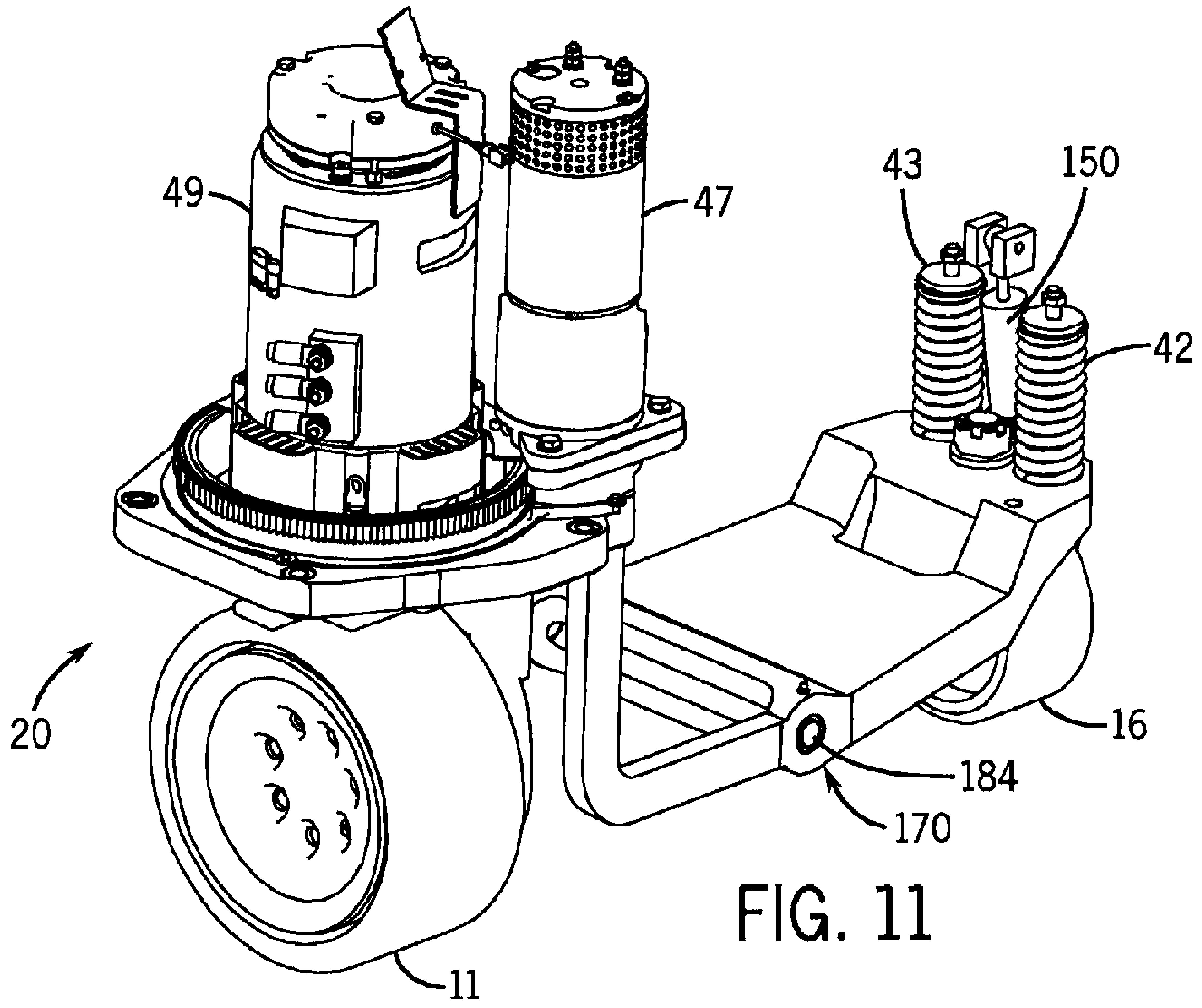

49
47
43
150
42
20
16
184
170
11

FIG. 11

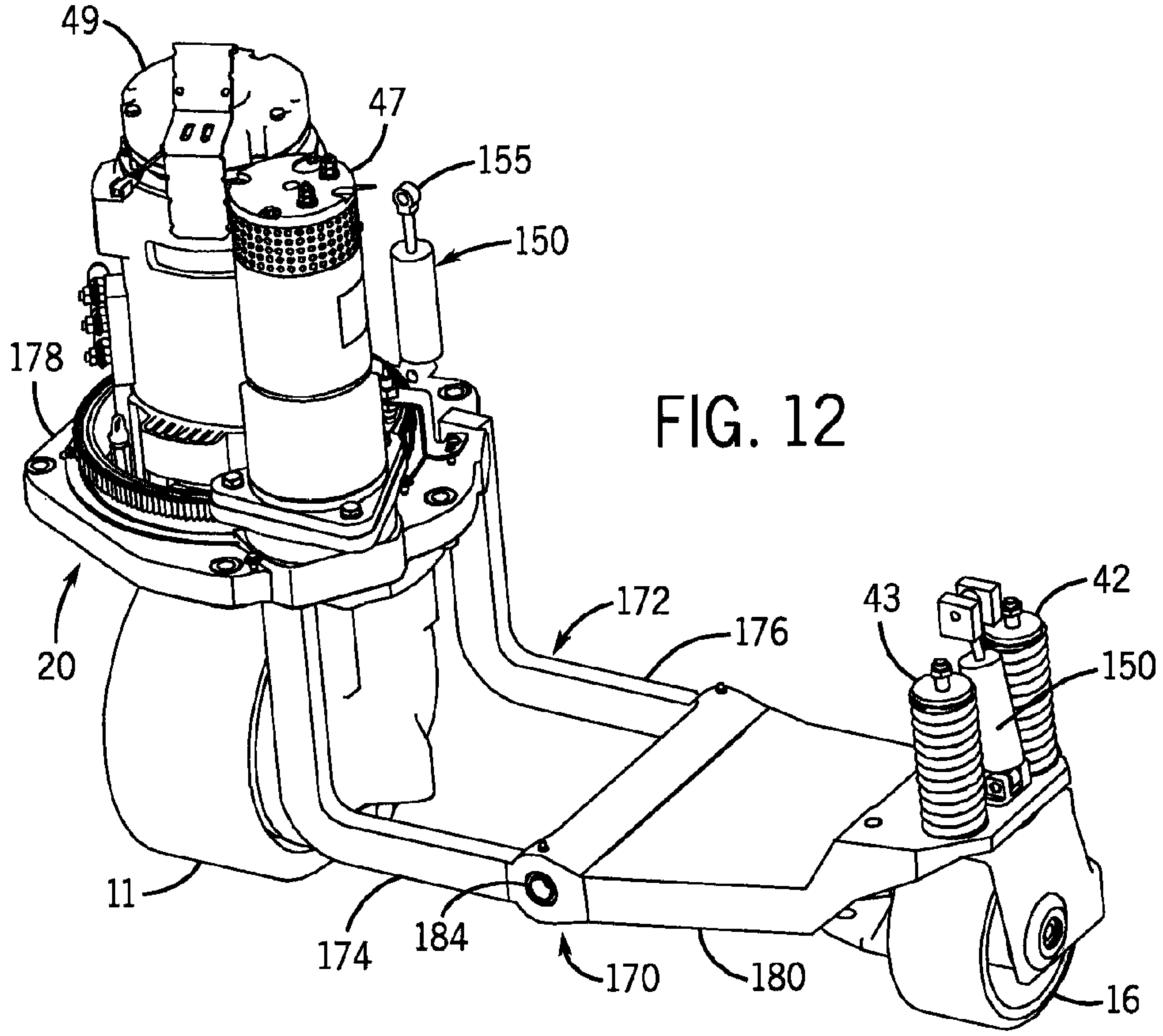

49
47
155
150
178
20
172
176
43
42
150
11
174
184
170
180
16

FIG. 12

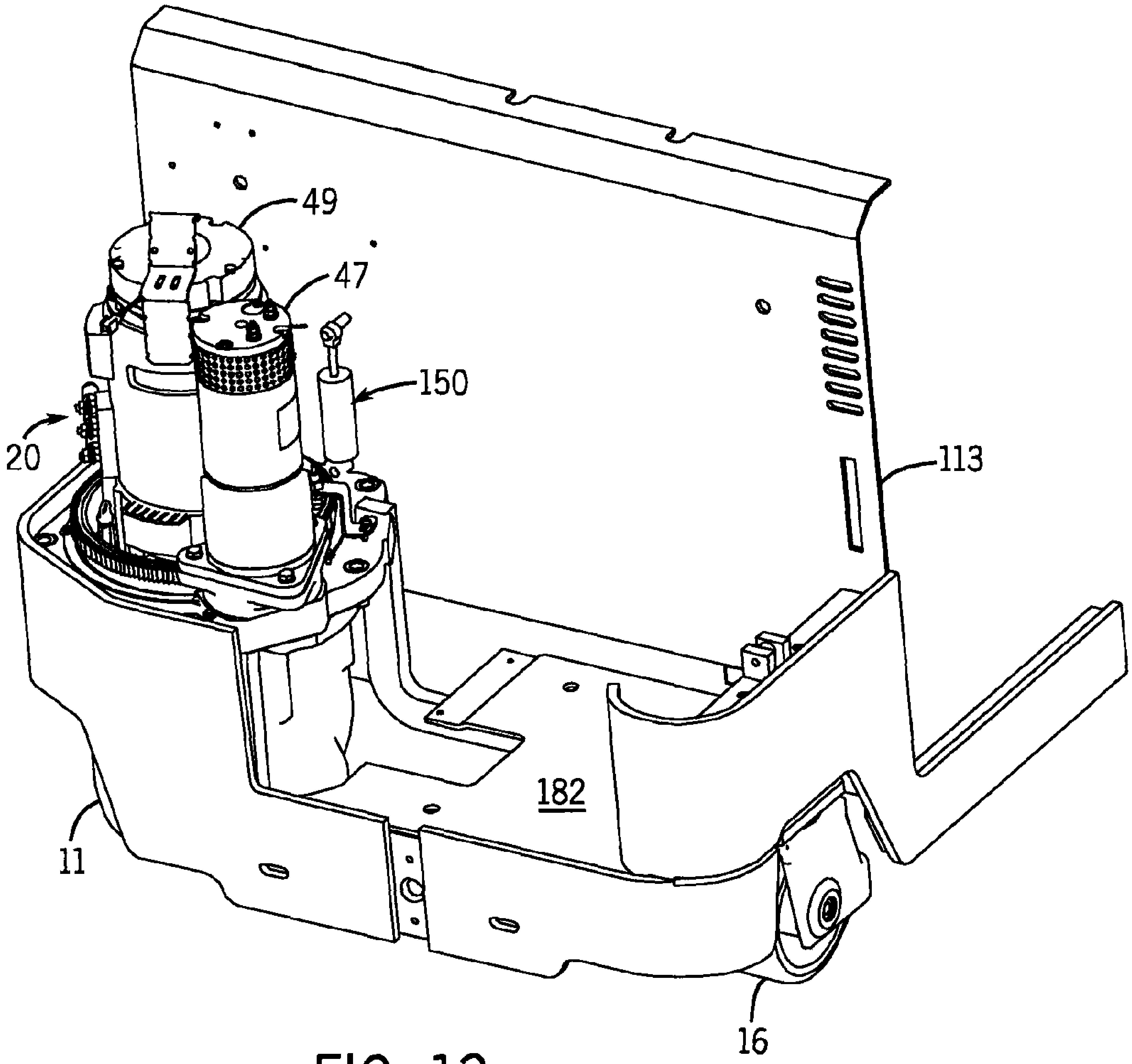


FIG. 13

MAGNETO-RHEOLOGICAL INERTIAL DAMPING SYSTEM FOR LIFT TRUCKS

CROSS-REFERENCE TO RELATED APPLICATION

Not applicable.

STATEMENT CONCERNING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not applicable.

FIELD OF THE INVENTION

This invention relates to material handling apparatus, and more particularly, to improved arrangements for inertially damping the motion of the unpowered, suspended rear wheel commonly used on lift trucks.

BACKGROUND OF THE INVENTION

One class of narrow-aisle lift trucks employs a pair of unpowered non-steerable front wheels, or load wheels, a steerable powered drive wheel assembly rigidly mounted near one rear corner of the truck, and an unpowered vertically-sprung idler wheel assembly near the other rear corner of the truck. With all four wheels mounted on the same base frame, one wheel must be vertically sprung, or floor irregularities could result in loss of traction by the drive wheel. In some applications the vertically-sprung idler wheel assembly uses a free-wheeling, non-steered caster wheel which is self-steering. One early form of truck of that type is shown in U.S. Pat. No. 2,564,002. In various other applications the sprung idler wheel is not castered, but instead steered via a linkage. A truck of this latter type is shown in U.S. Pat. No. 3,392,797.

The suspended wheel is suspended from the frame of the truck by coil springs, a torsion bar or leaf springs as shown and described in U.S. Pat. No. 4,813,512, which is hereby incorporated by reference for its description of such devices. Lift trucks achieve significant economies when vehicle frames of a uniform type are used with either a castered idler wheel or a linkage-steered idler wheel. Provision of an idler wheel mounting arrangement which will readily accommodate either type of steering is disclosed in U.S. Pat. No. 3,392,797. In the idler wheel mounting arrangements disclosed in that patent, the pivot steering axis of the idler wheel is located somewhat inwardly from a lateral extremity of the truck to allow space for a castered wheel to swing. The springs used to oppose weight on the idler wheel must be aligned with the pivot or steering axis, so that they do not impose moments which would cause undue bearing wear, and hence the springs also must be located undesirably inwardly from the lateral extremity of the truck, where they tend to interfere with provisions of an unobstructed operator compartment and waste space.

One problem with prior art lift trucks is that they sway when the truck stops abruptly or abruptly changes direction or both. While such motion will not tip the truck, it can be disconcerting to an operator. Normally an operator will slow down and allow the tilt to naturally dissipate before resuming travel. Accordingly, such unwanted tilting or swaying reduces the efficiency of the operator and the overall productivity of lift truck operations.

U.S. Pat. No. 5,685,555 describes one method for providing a suspended idler wheel mounting arrangement wherein the suspension means has its motion dampened in order to limit the tilt of a lift truck following an abrupt stop or an abrupt change in direction. Here, a mechanical inertial damper is coupled between the suspended wheel and the frame. The inertial damper includes a pair of parallel outer plates, with a slider plate disposed between the plates. A pair of friction pads is provided between an outer plate and the slider plate, and frictionally engages the slider plate when the frame moves relative to the wheel to slow the relative motion between the frame and the wheel. An adjustable means, such as a belville washer or spring, is provided for adjusting pressure of the outer plates on the slider plate.

While this prior art system is effective in providing stability to the vehicle, this system can provide only a single level of damping during use, and thus cannot dynamically adjust for variations that occur in the height of the mast or the weight of the load. The present invention addresses these issues.

SUMMARY OF THE INVENTION

The present invention provides a shock absorbing system that minimizes truck dynamics, particularly in vehicles having tall masts, for use on uneven floors, and in vehicles that provide right angle stacking. The shock absorbing dampers of the present invention provide smoother ride characteristics and facilitate precision load handling by providing a stable ride for the operator.

In one aspect, the present invention provides a lift truck adapted to provide stability during use of the vehicle. The lift truck comprises a frame, with a motor and wheels mounted on the frame. At least one wheel is driven by the motor and another wheel is suspended from the frame by a spring. A movable lift mast is mounted on the frame for vertically extending and retracting. The lift mast includes a mass sufficient to tilt the frame of the truck such that a portion of the frame adjacent the suspended wheel changes its relative position with respect to ground when the truck stops abruptly or changes direction abruptly. A fork is adapted to move along the mast. A sensor is provided for producing a feedback signal indicating at least one of a height of the mast, a weight of a load on the fork, and a speed of the lift truck. A magneto-rheological damper is coupled between the suspended wheel and the frame. A vehicle control system is adapted to monitor the feedback signal and to drive the magneto-rheological damper to alter a damping force based on the feedback for speed, height or weight.

In another aspect of the invention, the vehicle control system is further adapted to drive the damper to a maximum damping force when the feedback signal exceeds a respective one of a speed, height or weight maximum damping value. The vehicle control system can also be adapted to drive the damper to a selected damping force value between the minimum damping force and the maximum damping force as a function of the feedback signal. The selected damping force can be also selected as a function of the ratio of the feedback to a maximum rated value for the lift truck.

In another aspect of the invention, the lift truck further comprises a second sensor for producing a second feedback signal indicative of another of the height of the mast, a weight of a load on the fork, and a speed of the lift truck. The lift truck can also include a third sensor for sensing the remaining height, weight, or speed parameter.

In yet another aspect of the invention the minimum damping value and the maximum damping value are calculated as a function of the rated maximum value of the parameters associated with each of the respective height of the mast, weight of a load on the fork, and speed of the lift truck.

The foregoing and other objects and advantages of the invention will appear in the detailed description which follows. In the description, reference is made to the accompanying drawings which illustrate a preferred embodiment of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an elevation view of a lift truck with its mast extended and supporting a load.

FIG. **2** is a rear elevation view of one form of lift truck incorporating a preferred form of the invention, with certain parts cut away and certain parts omitted for sake of clarity.

FIG. **3** is a downward section view taken at lines **3**-**3** in FIG. **2**.

FIG. **4** is a partial perspective and partial cut away view of a lift truck showing an inertial damper on the suspended wheel.

FIG. **5** is a front elevation view of the damper mounted between two coil springs.

FIG. **6** is a back elevation view of the damper mounted between two coil springs.

FIG. **7** is a block diagram of a control system for the lift truck of FIG. **1**.

FIG. **8** is a graph illustrating the current applied for percentages of maximum rated height, weight and speed levels.

FIG. **9** is a graph illustrating the current applied for percentages of maximum rated height, weight and speed levels for a specific vehicle.

FIG. **10** is a partial view of a lift truck constructed in accordance with a second embodiment of the invention.

FIG. **11** is a perspective view of a suspension system provided in the lift truck of FIG. **10**.

FIG. **12** is a second perspective view of a suspension system provided in the lift truck of FIG. **10**.

FIG. **13** is another partial view of the lift truck of FIG. **10**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

FIGS. **1** and **2** illustrate a lift truck **100** constructed in accordance with one embodiment of the present invention. Referring first to FIG. **1**, the truck **100** comprises a mast **110** including a fork **112** that is moveable along the mast **110** to raise and lower a load **114**. The mast **110** and a housing **113** are coupled to a base frame **116** of the truck **100**, and a steerable powered drive wheel assembly **20** and a vertically sprung idler wheel assembly **32** support the truck **100** below the base frame **116**. As described below, the idler wheel assembly **32** includes a magneto-rheological damper for stabilizing the truck **100** during operation and preferably also includes a spring assembly.

Referring now also to FIG. **2**, a cutaway view of the housing **113** of the lift truck **100** is shown. The drive wheel assembly **20** includes a traction motor **49** which drives a drive wheel **11**, and a steering motor **47** that is fixedly mounted relative to the base frame **116** of the truck **100** and is operated by a conventional steering control **16** (FIG. **4**), which is controlled by the operator to select a direction of motion for the drive wheel **11** and truck **100**. The drive wheel assembly **20** can be constructed, for example, as described in U.S. Pat. No. 5,685,555, which is incorporated by reference for its description of this assembly and the associated steering linkages. Various other methods of constructing a drive wheel assembly will be apparent to those of skill in the art.

Referring still to FIG. **2**, the idler wheel assembly **32** is coupled to the housing **113** on an opposing side of the housing **113** from the drive wheel **11**. Referring now also to FIG. **5**, the idler wheel assembly **32** is shown journalled by means of a roller thrust bearing **40** near the outer end of a rigid A-frame arm, or lever member **34**, which is shown pivotally mounted on the base frame **116** of the truck **100**, near the lateral center of the truck **100**, by trunnion bearings **35** so that A-frame lever member **34** may rotate limited amounts about a horizontal longitudinally-extending axis x-x (FIG. **3**). A pair of compression springs **42**, **43** are shown interposed between the outer end of the A-frame lever member and a plate affixed to the base frame **116** of the truck **100**. Hence springs **42**, **43** compress in accordance with the vertical weight imposed on the idler wheel **16**, and as the truck **100** travels over irregular floor surfaces the idler wheel **16** may move upwardly and downwardly relative to the frame **116** of the truck **100** to insure that adequate weight to provide traction is always imposed on the powered drive wheel **11** of drive unit **20**. As shown in FIG. **1**, when truck **100** stops abruptly or abruptly changes direction, the springs **42**, **43** are compressed and oscillate, thereby causing the mast **110** to oscillate, for example, in the direction of arrow **103**. Such oscillation is enhanced by a load **114** carried on fork **112** that is extended to the top of the mast **110**. Although a specific direction of oscillation is shown here, the induced oscillation can be in a lateral direction, in a longitudinal direction, or both.

As floor surface irregularities cause the A-frame lever member **34** to rotate about axis x-x, the steering axis of the idler wheel assembly departs slightly from the vertical, and because the idler wheel steering shaft is journalled in lever member **34** for rotation about a fixed axis, the slight rotation of the lever member causes floor contact of the idler wheel **16** to vary between the inside and outside edges of the idler wheel tire. Appreciable rotation of lever member **34** occurs when floor irregularities are encountered, when there is a rapid change in motion, or when the brakes are applied quickly.

Referring still to FIG. **2**, idler wheel assembly **32** includes an idler wheel **16** (shown partially cutaway in FIG. **2**), and a vertical pivot or steering shaft **52** (FIG. **3**). Referring now also to FIGS. **4**, **5**, and **6**, the idler wheel assembly **32** comprises a plate **44** that is coupled to an inside wall of the housing **113**, and springs **42** and **43** are coupled between the plate **44** and the lever member **34**, substantially in parallel with a magneto-rheological damper **150**. The damper **150** includes a housing **149** that contains a magneto-rheological fluid, and an extendable arm **151** that extends and retracts from the housing **149**. A ring connector **153** is provided at the end of the arm **151**, and a ring connector **155** is provided at the opposing end of the housing. When a magnetic field is applied to the fluid, by applying a voltage and current to the fluid in the housing **149**, the fluid changes from a liquid to a near solid, increasing the damping force of the damper **150**. Although a number of commercial devices are available for providing this function, one example of a magneto-rheological device suitable in the present application is the RD-1005-3 MR Damper from Lord Corporation of Cary N.C.

Referring still to FIGS. **5** and **6**, a mounting member **161** is coupled to the plate **44**, and a mounting member **163** is coupled to the lever arm **34**. Each of the mounting members **161** and **163** include two legs, which are positioned on opposing sides of the ring connectors **153** and **155**, respectively, at opposing ends of the damper **150**, and include bores that axially align with bores in the legs (not shown). Fasteners, **157** and **159**, are connected to the mounting members **161** and **163** through the ring connector **153** and **155**, respectively, coupling the opposing ends of the damper **150** to the plate **44** and the lever arm **34**.

Referring now to FIG. **7**, a block diagram of a control system for one embodiment of a lift truck **100** constructed in accordance with the present invention is shown. The lift truck **100** comprises a vehicle control system **12** which receives operator input signals from the operator control handle **14**, the steering wheel **17**, a key switch **18**, and the floor switch **19** and, based on the received signals, provides command signals to each of a lift motor control **23** and a drive system **25** including both a traction motor control **27** and a steer motor control **29**. The drive system **25** provides a motive force for driving the truck **100** in a selected direction, while the lift motor control **23** drives forks **112** along the mast **110** to raise or lower a load **114**. The lift truck **100** and vehicle control system **12** are powered by one or more battery **37**, coupled to the vehicle control system **12**, drive system **25**, steer motor control **29**, and lift motor control **23** through a bank of fuses or circuit breakers **39**.

As noted above, the operator inputs include a key switch **18**, floor switch **19**, steering wheel **17**, and an operator control handle **14**. The key switch **18** is activated to apply power to the vehicle control system **12**, thereby enabling the lift truck **100**. The floor switch **19** provides a signal to the vehicle control system **12** for operating the brake **22** to provide a deadman braking device, disabling motion of the vehicle unless the floor switch **19** is activated by the operator.

The operator control handle **14** provides a travel request signal to the vehicle control system **12**. Typically, the handle **14** is rotated in a vertical plane to provide a travel direction and speed command of motion for the lift truck **10**, and includes a switch **15** located on the top of the handle **14** that can provide a tilt up/down function when activated in the forward and reverse directions and a sideshift right and left function when activated to the right and left directions. A plurality of control actuators **41** located on the handle **14** provide a number of additional functions, and can include, for example, a reach push button, a retract push button, and a horn push button as well as a potentiometer providing a lift function. A number of other functions could also be provided, depending on the construction and intended use of the lift truck **10**.

The traction motor control **27** drives the traction motor **49** which is connected to wheel **11** to provide motive force to the lift truck. The speed and direction of the traction motor **49** and associated wheel **11** is selected by the operator from the operator control handle **14**, and is typically monitored and controlled through feedback provided by a speed sensor **45** which can be an encoder or other feedback device coupled to the traction motor **49**. The wheel **11** is also connected to friction brake **22** through the traction motor **49**, to provide both a service and parking brake function for the lift truck **10**. The friction brake **22** can be a spring-activated brake that defaults to a "brake on" position, such that the switch **20** and associated brake **22** therefore provide the deadman braking function. The operator must provide a signal indicating that the deadman brake is to be released to drive the truck, here provided by the floor switch **19**, as described above. The traction motor **49** is typically an electric motor, and the associated friction brakes **22** can be either electrically operated or hydraulically operated devices. Although one friction brake **22**, motor **49**, and wheel **11** are shown, the lift truck **100** can include one or more of these elements. Various other types of braking systems could also be used.

The steer motor control **29** is connected to drive a steer motor **47** and associated steerable wheel **11** in a direction selected by the operator by rotating the steering wheel **17**, described above. The direction of rotation of the steerable wheel **11** determines the direction of motion of the lift truck **10**.

The lift motor control **33** provides command signals to control a lift motor **51** which is connected to a hydraulic circuit **53** for driving the forks **112** along the mast **110**, thereby moving the load **114** up or down, depending on the direction selected at the control handle **14**. In some applications, the mast **110** can be a telescoping mast, as shown here. Here, additional hydraulic circuitry is provided to raise or lower the mast **110** as well as the forks **112**. Sensors **117** and **115** can be provided for monitoring the height of the mast **110** and the weight of the load **114**, respectively. The sensor **117** can be, for example, an encoder driven by a belt or cable. The sensor **115** can be a transducer that measures pressure, which is then converted to a weight by the vehicle control system **12** as a function of the pressure of the hydraulic fluid. Based on the height of the mast **110**, the weight of the load **114**, and the speed of the truck **100**, the vehicle control system **12** drives the magneto-rheological damper **150** to stabilize the lift truck **100**, as described more fully below. Although specific sensors are discussed above, various other sensing methods can be used. For example, weight can be measured using fork scales, and height by using ultrasonic, radar, laser, or infrared measuring devices. Other types of measuring devices will be apparent to those of skill in the art.

Referring again to FIG. **1**, in operation, as the truck **100** moves backward and abruptly stops, the mast **110** can begin to tilt in the direction indicated by arrow **103** and pivot about a line between the drive wheel contact with the floor and the right front load wheel contact with the floor so that the base **116** of the truck **100** compresses the springs **42**, **43**. Without the damper **150** the truck **100** would oscillate aided by springs **42**, **43**. Once oscillation begins in typical prior art vehicles, the truck continues to oscillate until the oscillation is dissipated through friction inherent in the suspension members. However, with the magneto-rheological damper **150**, the vehicle control system **12** can activate the magneto-rheological damper **150** to retard the motion of the frame **116**.

Referring still to FIG. **7** and now also to FIG. **8**, a graph illustrating the application of the damper **150** is shown. As shown in the graph of FIG. **8**, current can be applied to the damper **150** by the vehicle control system **12** to adjust the damping force of damper **150** under varying height, weight, and speed conditions as shown. During operation, the vehicle control system **12** receives speed feedback from sensor **45**, height feedback from the height sensor **117** and weight feedback from the weight sensor **115**. Based on these feedback signals, the vehicle control system **12** adjusts the current applied to the damper **150**, thereby adjusting the damping force applied by the damper **150**.

Referring now specifically to FIG. **8**, when no load is on the mast **110** and the mast **110** is in a lowered state, the vehicle control system **12** retains the damping force of the damper **150** at a minimum value. When any of the speed, weight, and height parameters reaches a predetermined minimum damping value, the vehicle controller **12** begins applying current to the damper **150**, such that the damper **150** begins applying a damping force at a selected value. The applied current is ramped up at a steady rate, shown here as linear, until any of the speed of the vehicle, the height of the mast, or the weight of the load reaches a maximum damping value. At this level, the vehicle control system **12** drives the damper **150** to a maximum damping force level, and the vehicle controller **12** continues to apply the maximum current until the mast height, load weight, and speed all fall below the maximum value. By adjusting the damper as described, additional stability is provided when lifting or transporting a heavy load, when driving the truck with the mast **110** in an extended position, and when driving the lift truck **100** at a relatively high rate of speed or abruptly changing the direction of travel. When the damper **150** is activated, the truck **100** receives additional stabilizing support, thereby limiting instability, and truck sway or oscillation. When the damper **150** is not active, as, for example, during unloaded operation, the suspension of the truck is relatively soft, limiting operator fatigue.

Referring still to FIG. **8**, it has been shown experimentally that applying a damping force when the speed of the lift truck, weight of the load, or height of the mast exceeds 25% of the maximum rated value provides stability to the vehicle, while maintaining a soft ride when damping is not required. To maintain stability, the amount of damping can be increased linearly as the speed, height or weight increase between 25% and 50% of the maximum rated value. After any of the speed, height, or weight values exceeds 50% of the maximum rated value, the maximum damping value is applied until all of these values falls below 50%. Although no example is shown here, it will be apparent that these factors can be varied, while generally increasing damping as the height, weight, and/or speed of the vehicle increases and decreasing the damping as these parameters decrease.

Referring now to FIG. **9**, in one specific example, the speed of the vehicle varies from zero to eight miles per hour, the weight of a load that can be carried by the forks **112** of the vehicle is limited to about four thousand pounds, and the mast is extendable between zero and four hundred inches. Here, the vehicle control system **12** applies no current to the damper **150**, and the applied damping force is therefore is substantially zero, until at least one of the speed, weight, and height exceeds a minimum damping value. Here, specifically, the vehicle controller drives the controller at zero amps until the speed of the lift truck **100** exceeds two miles per hour, the weight of the load **114** carried on the fork **112** exceeds one thousand pounds, or the height of the mast exceeds one hundred inches. When any of these minimum damping values are exceeded, the vehicle controller **12** beings to apply current to the damper **150**, such that the damper **150** begins applying a damping force to the idler wheel assembly **32**. The current applied by the vehicle controller **12** is ramped up at a steady rate until any of the speed, weight, or height values exceeds a maximum damping value, specifically four miles per hour, two thousand pounds or two hundred inches, respectively. At this level, the vehicle controller **12** applies the maximum current of one amp to the damper **150**, providing a counterforce of about 1500N and continues to apply this level of damping until each of the speed, height, and weight falls below the maximum damping value. Additionally, although the damping force is shown increasing linearly, the force can be stepped up in various range levels or otherwise adjusted based on the characteristics of the vehicle.

Although the vehicle control system **12** is described above as receiving input from each of the speed sensor **44**, height sensor **117** and weight sensor **115**, the damper **150** can also be adjusted based on input from any one or more of these sensors. Furthermore, although specific percentages for adjusting the damping are described above, more generally speaking, the damping force should be increased as the vehicle speed increases, the height of the mast increases and the weight of the load increases. Using these guidelines, the damping of the vehicle can be adjusted for different levels.

Referring now to FIGS. **10-13**, an alternative embodiment of a lift truck including a magneto-rheological damping systems is shown, wherein like numbers are used for elements described with reference to FIGS. **1-6** above. As described

above, the lift truck **100** includes a drive wheel assembly **20** including a traction motor **49**, steering motor **47**, and drive wheel **11**. An idler wheel **16** is also suspended from the frame. Here, however, the suspension system provided below the floor **182** is a walking beam suspension system **170**.

Referring now to FIGS. **11** and **12**, the walking beam suspension system **170** includes a first beam assembly **172**, and a second beam assembly **180** that are pivotably coupled together at a pivot point **184**. The idler wheel **16** is coupled to the distal end of the second beam assembly **180**, and the drive wheel assembly **20** is coupled to the distal end of the first beam assembly **172**. As shown here, the distal end of the first beam assembly **172** can comprise a first and second L-shaped beams **174** and **176**. Optionally, springs **42** and **43** can be coupled to the second beam assembly **180** at one end, and to a plate **44** coupled to an inside wall of the housing **113** as described above with reference to FIG. **4**. To stabilize the truck and limit oscillations, a magneto-rheological damper **150** can be coupled between the second beam assembly **180** and a plate **44** that is coupled to an inside wall of the housing **113**, as described above with reference to FIGS. **5** and **6**. Alternatively, or in addition to the magneto-rheological damper **150**, a magneto-rheological damper **184** can be coupled to the drive motor assembly **20** as, for example, between a motor mounting plate **178** and a substantially vertical toe plate that forms part of the housing **113** (FIG. **13**). The magneto-rheological damper **184** can also be coupled anywhere between the motor mounting plate **178** or first beam assembly **172** and the housing **113**, or more generally between the suspension system and the housing.

A preferred embodiment of the invention has been described in considerable detail. Many modifications and variations to the preferred embodiment described will be apparent to a person of ordinary skill in the art. It should be understood, therefore, that the methods and apparatuses described above are only illustrative and do not limit the scope of the invention, and that various modifications could be made by those skilled in the art that would fall within the scope of the invention. To apprise the public of the scope of this invention, the following claims are made:

I claim:

1. A lift truck comprising:

a frame;

a motor and wheels mounted on the frame with at least one wheel driven by the motor and another wheel suspended from the frame;

a movable lift mast mounted on the frame for vertically extending and retracting and having a mass sufficient to tilt the frame of the truck such that a portion of the frame adjacent the suspended wheel changes its relative position with respect to ground when the truck stops abruptly or changes direction abruptly;

a magneto-rheological damper coupled between the suspended wheel and the frame;

a fork adapted to move along the mast;

a sensor for producing a feedback signal indicating at least one of a height of the mast, a weight of a load on the fork, and a speed of the lift truck; and

a vehicle control system monitoring the feedback signal and adjusting a damping force of the magneto-rheological damper based on the feedback signal, said vehicle control system driving the damper to a selected damping force value between a minimum damping force and a maximum damping force as a function of a level of the feedback signal.

2. The lift truck as recited in claim **1**, wherein the vehicle control system adjusts the damping force when the feedback signal exceeds a respective one of a speed, a height or a weight minimum damping value.

3. The lift truck of claim **1**, wherein the vehicle control system drives the magneto-rheological damper at a minimum damping force when the feedback signal is below a respective one of a speed, a height or a weight minimum damping value.

4. The lift truck as recited in claim **1**, wherein the vehicle control system drives the damper to a maximum damping force when the feedback signal exceeds a respective one of a speed, height or weight maximum damping value.

5. The lift truck as recited in claim **1**, wherein the selected damping force value is selected as a function of the ratio of the feedback to a respective one of a speed, a height, and a weight maximum rated value for the lift truck.

6. The lift truck as recited in claim **1**, wherein the selected damping force ramps linearly between the minimum and the maximum damping force.

7. The lift truck as recited in claim **1**, further comprising a second sensor for producing a second feedback signal indicative of another of the height of the mast, a weight of a load on the fork, and a speed of the lift truck.

8. The lift truck as recited in claim **7**, wherein the vehicle control system monitors the second feedback signal and drives the magneto-rheological damper to increase a damping force when at least one of the feedback signal and the second feedback signal exceeds a respective minimum damping value.

9. The lift truck as recited in claim **7**, wherein the vehicle control system drives the magneto-rheological damper at a maximum damping force when one of the first and second feedback signals exceeds a corresponding maximum damping value, and to decrease the damping force below the maximum damping force when each of the feedback signal and the second feedback signal fall below a corresponding maximum damping value.

10. The lift truck of claim **7**, further comprising a third sensor for producing a third feedback signal indicative of another of the height of the mast, a weight of a load on the fork, and a speed of the lift truck, and wherein the vehicle control system drives the magneto-rheological damper to increase the damping force when any of the feedback signal, the second feedback signal, and the third feedback signal exceeds a corresponding minimum damping value.

11. The lift truck as recited in claim **10**, wherein the vehicle control system drives the magneto-rheological damper at a maximum damping force when one of the feedback signal, the second feedback signal, and the third feedback signal exceeds a corresponding maximum damping value, and decreases the damping force below the maximum damping force when each of the feedback signal, the second feedback signal, and the third feedback signal fall below a corresponding maximum damping value.

12. The lift truck as recited in claim **10**, wherein the minimum damping value and the maximum damping value are selected as a function of the rated maximum value of a corresponding one of a height of the mast, a weight of a load on the fork, and a speed of the lift truck.

13. The lift truck as recited in claim **1**, wherein the sensor is a height sensor.

14. The lift truck as recited in claim **13**, further comprising a weight sensor and a speed sensor, and wherein the vehicle control system is adapted to monitor each of the weight feedback, the height feedback, and the speed feedback.

15. The lift truck of claim **1**, further comprising a spring, and wherein the wheel suspended from the frame is suspended by the spring.

16. A lift truck comprising:

a frame;

a motor and wheels mounted on the frame with at least one wheel driven by the motor and another wheel suspended from the frame by a spring;

a movable lift mast mounted on the frame for vertically extending and retracting and having a mass sufficient to tilt the frame of the truck such that a portion of the frame adjacent the suspended wheel changes its relative position with respect to ground when the truck stops abruptly or changes direction abruptly;

a magneto-rheological damper coupled between the suspended wheel and the frame;

a fork adapted to move along the mast;

a height sensor for producing a height feedback signal indicating the height of the mast;

a weight sensor for producing a weight feedback signal indicating a weight of a load on the fork;

a speed sensor for producing a speed feedback signal indicating a speed of the lift truck; and

a vehicle control system monitoring the height feedback signal, the weight feedback signal, and the speed feedback signal, driving the magneto-rheological damper to increase a damping force when at least one monitored feedback signal exceeds a respective speed, height or weight minimum damping value, and driving the magneto-rheological damper to decrease the damping force when the speed feedback signal, height feedback signal and weight feedback signal are all below the respective minimum damping value, said vehicle control system driving the damper to a selected damping force value between the minimum damping force and a maximum damping force as a function of a level of the feedback signal.

17. The lift truck of claim **16**, wherein the vehicle control system drives the damping force to a maximum value when at least one of the monitored feedback signals exceeds a respective speed, height or weight maximum damping value.

18. The lift truck of claim **16**, wherein the vehicle control system drives the damping force to a selected value between the minimum and the maximum damping value when at least one of the monitored feedback signals exceeds a respective speed, height or weight minimum damping value and each of the monitored feedback signals is below the respective maximum damping value.

19. The lift truck of claim **16**, wherein the vehicle control system determines the selected value as a function of the one of the speed, height or weight feedback signal that is closest to a rated maximum for the selected parameter.

20. The lift truck of claim **16**, further comprising a spring, and wherein the wheel suspended from the frame is suspended by the spring.

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